SOIL BIOLOGY & ECOLOGY:

THE BASICS

Dan Răzvan Popoviciu

Bentham Books

Soil Biology & Ecology: The Basics

Authored by

Dan Răzvan Popoviciu
"Ovidius", University Constanța
România Faculty of Natural Sciences
and Agricultural Sciences
Romania

Soil Biology & Ecology: The Basics

Author: Dan Răzvan Popoviciu

ISBN (Online): 978-981-5313-29-1

ISBN (Print): 978-981-5313-30-7

ISBN (Paperback): 978-981-5313-31-4

© 2024, Bentham Books imprint.

Published by Bentham Science Publishers Pte. Ltd. Singapore. All Rights Reserved.

First published in 2024.

BENTHAM SCIENCE PUBLISHERS LTD.

End User License Agreement (for non-institutional, personal use)

This is an agreement between you and Bentham Science Publishers Ltd. Please read this License Agreement carefully before using the book/echapter/ejournal (**"Work"**). Your use of the Work constitutes your agreement to the terms and conditions set forth in this License Agreement. If you do not agree to these terms and conditions then you should not use the Work.

Bentham Science Publishers agrees to grant you a non-exclusive, non-transferable limited license to use the Work subject to and in accordance with the following terms and conditions. This License Agreement is for non-library, personal use only. For a library / institutional / multi user license in respect of the Work, please contact: permission@benthamscience.net.

Usage Rules:

1. All rights reserved: The Work is the subject of copyright and Bentham Science Publishers either owns the Work (and the copyright in it) or is licensed to distribute the Work. You shall not copy, reproduce, modify, remove, delete, augment, add to, publish, transmit, sell, resell, create derivative works from, or in any way exploit the Work or make the Work available for others to do any of the same, in any form or by any means, in whole or in part, in each case without the prior written permission of Bentham Science Publishers, unless stated otherwise in this License Agreement.
2. You may download a copy of the Work on one occasion to one personal computer (including tablet, laptop, desktop, or other such devices). You may make one back-up copy of the Work to avoid losing it.
3. The unauthorised use or distribution of copyrighted or other proprietary content is illegal and could subject you to liability for substantial money damages. You will be liable for any damage resulting from your misuse of the Work or any violation of this License Agreement, including any infringement by you of copyrights or proprietary rights.

Disclaimer:

Bentham Science Publishers does not guarantee that the information in the Work is error-free, or warrant that it will meet your requirements or that access to the Work will be uninterrupted or error-free. The Work is provided "as is" without warranty of any kind, either express or implied or statutory, including, without limitation, implied warranties of merchantability and fitness for a particular purpose. The entire risk as to the results and performance of the Work is assumed by you. No responsibility is assumed by Bentham Science Publishers, its staff, editors and/or authors for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products instruction, advertisements or ideas contained in the Work.

Limitation of Liability:

In no event will Bentham Science Publishers, its staff, editors and/or authors, be liable for any damages, including, without limitation, special, incidental and/or consequential damages and/or damages for lost data and/or profits arising out of (whether directly or indirectly) the use or inability to use the Work. The entire liability of Bentham Science Publishers shall be limited to the amount actually paid by you for the Work.

General:

1. Any dispute or claim arising out of or in connection with this License Agreement or the Work (including non-contractual disputes or claims) will be governed by and construed in accordance with the laws of Singapore. Each party agrees that the courts of the state of Singapore shall have exclusive jurisdiction to settle any dispute or claim arising out of or in connection with this License Agreement or the Work (including non-contractual disputes or claims).
2. Your rights under this License Agreement will automatically terminate without notice and without the

need for a court order if at any point you breach any terms of this License Agreement. In no event will any delay or failure by Bentham Science Publishers in enforcing your compliance with this License Agreement constitute a waiver of any of its rights.

3. You acknowledge that you have read this License Agreement, and agree to be bound by its terms and conditions. To the extent that any other terms and conditions presented on any website of Bentham Science Publishers conflict with, or are inconsistent with, the terms and conditions set out in this License Agreement, you acknowledge that the terms and conditions set out in this License Agreement shall prevail.

Bentham Science Publishers Pte. Ltd.
80 Robinson Road #02-00
Singapore 068898
Singapore
Email: subscriptions@benthamscience.net

CONTENTS

PREFACE

Atlhough few people acknowledge it, soil is one of the environments hosting the highest biodiversity on this planet. A multitude of micro-and macroorganisms, bacteria, fungi, protists, plants and animals populate the various types of soil.

Yet, a really remarkable thing about soil is not just its enormous biodiversity, but also the variety and complexity of interactions among present organisms. At this level, we can find complex symbioses, competition, predation and parasitism. These interactions are essential to the continuous recycling of bioelements, in decomposing organic matter and making available again its various components.

Thus, soil has a crucial contribution to the very existence of Earth's biosphere. It provides nutritional support to all land-based ecological communities and, is also the basis of any agricultural production, thus, of our everyday food.

This is why knowledge of all these aspects of soil biology and ecology is important to naturalists. This book is conceived as a guide to students, specialists and all people interested in natural sciences.

Dan Răzvan Popoviciu
"Ovidius", University Constanța
România Faculty of Natural Sciences
and Agricultural Sciences
Romania

CHAPTER 1

Soil as a Living Habitat, General Considerations

Abstract: Soils cover most of the Earth's landmasses. Soil is a complex system, under continuous evolution and in perpetual relation to the atmosphere, hydrosphere, lithosphere, and biosphere. It is polyphasic, composed of a solid (mineral and organic) fraction, but also of liquid and gaseous fractions. A key aspect is its stratification into several horizons. This complex structure determines the living conditions being provided to the local biota, but also a major diversification of soil types on our planet.

Keywords: Classification, Life conditions, Soil, Stratification, Structure.

INTRODUCTION

Understanding soil biota requires, first of all, understanding soil as a living environment.

The key aspects of this are defining and delineating soil from other environments, knowing its characteristics, its structural features, and the life conditions it offers to inhabiting organisms.

Defining Soil

A key issue in studying this environment is how to clearly define and delimit it.

According to the Soil Science Society of America, soil can be briefly defined as "*The unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants*" [1].

The same society also gives a more precise definition, stating that soil is "*The unconsolidated mineral or organic matter on the surface of the earth that has been subjected to and shows effects of genetic and environmental factors of climate (including water and temperature effects), and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time*" [1].

According to this definition, soil consists of both organic and inorganic components, which are subjected to continuous transformations, due to various

Dan Răzvan Popoviciu
All rights reserved-© 2024 Bentham Science Publishers

environmental factors specific to our planet. Thus, the soil is clearly distinct from the *regolith* covering the surfaces of other planets in our Solar System – a layer of variable thickness, made up of mobile mineral fragments, but devoid of organic matter (or, at least not in substantial amounts), lifeforms and lacking exposure to a hydrosphere or even atmosphere [2].

Natural Resources Conservation Service (government entity subordinated to the United States Department of Agriculture), defines soil as "*Soil is a natural body comprised of solids (minerals and organic matter), liquid, and gases that occur on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment.*" [3].

Thus, the soil is formed of diverse components, has its specific layering, and is under continuous evolution, but it is also characterized from a functional point of view, by its ability to support plant life. The latter is connected to a key feature, typical to soil, that makes it clearly distinct from non-soils: fertility.

Even more important, NRCS states there are some physical boundaries between soils and other environments. The upper limit is the interface between the soil and air or a shallow water layer.

In aquatic environments, it is necessary to distinguish soil from *sediments* (sand, mud, *etc.*). The arbitrary limitation, according to NRCS is that the water layer should be less than 2.5 m thick so that the underlying material could be considered as soil. This would correspond to the maximum insertion limit of rooted water plants [3].

It is also important to define the lower limits of soil. Unlike underlying materials, the soil is characterized by a continuous interaction with the atmosphere and hydrosphere. Most lifeforms (including plant roots) dwell within a thin layer of Earth's lithosphere. This although there are living beings (mostly microorganisms) that can be found up to 5 km deep [4].

So, as a practical maximum lower limit, soil scientists take a depth of 2 m [3].

Soil Characteristics

There are several key features that define soil:

• Soil is a **system**. This means that it includes various types of components, integrated in a functional ensemble.

- It is a **natural** system because it is formed under the influence of natural, biotic, and abiotic factors.

- It is **complex** because the factors conditioning its genesis and structure are numerous.

- It is **polyphasic**, its genesis involves different successive temporal stages.

- It is h**eterogeneous**, being formed of components having different physical states (mainly solid, but also liquid and gaseous).

- It is **polydisperse**, meaning that its solid phase – dominant – is found under different degrees of dispersion: coarse dispersions (suspensions: sand and dust grains), colloidal dispersions (such as some heavily soluble hydroxides, humus, and clay), and molecular/ionic dispersions (soluble salts).

- It is an **open** system, being constantly involved in matter and energy exchange processes with Earth's lithosphere, hydrosphere, atmosphere, and biosphere.

- It is a **polyfunctional** system, performing multiple functions [5].

Morphological Characterization of Soil

As a complex system, soil is made up of different components. This complexity can be seen, for instance, in its vertical stratification (as soil consists of several **horizons**).

Horizon succession usually follows the scheme shown in Fig. (**1**) (obviously, this is a general model, while variations can occur from one soil type to another; some horizons may be missed, while others are present).

Thus, we may successively encounter:

- **O horizon**, superficial, rich in organic matter. It is mostly developed in forest areas, as well as in some grasslands (pastures, prairies). Its presence is due to plant tissue decomposition (especially leaves from woody plants). It can be subdivided into three categories, or sub-horizons, depending on the degree of organic matter decomposition: plant litter (Ol), fermentation horizon (Of), and humification horizon (Oh).

- **A horizon**, also called surface horizon or topsoil, contains a mix of organic and mineral matter.

CHAPTER 2

Soil Biodiversity, Microbiota

Abstract: Microorganisms form the bulk of soil biota. Having densities of hundreds of millions per gram, bacteria are the dominant organisms. They are the starting point of most trophic chains, they ensure a major part of soil functionality as an ecosystem and they effectively create soil, especially by breaking down organic matter. Their taxonomic diversity is enormous, such as the ecological one: heterotrophs, photoautotrophs, chemoautotrophs, *etc.* Besides them, there are also archaea, viruses, different types of microalgae, and the eclectic group we usually call “protozoans”.

Keywords: Archaea, Bacteria, Microalgae, Protozoa, Subcellular entities.

INTRODUCTION

Soils are environments that host an impressive biodiversity (Fig. **1**). Indeed, numerous micro- and microorganisms use soil as a home (permanently or temporarily), but also as a source of food. Among the different lifeforms that belong to soil biota, microorganisms are clearly dominant, in terms of number and biomass, but also functionality.

Just as in any other environment, biodiversity can be characterized using standard ecological indices. Abundance (A) is the number of individuals belonging to a given taxon. Dominance (D) is the percentual ratio between the number of individuals in a certain species and the total number of individuals in a soil sample. We can distinguish between subrecedent (<1.1%), recedent (1.2-2%), subdominant, dominant (2.1-5%), and eudominant (>10%) species. Constancy (C) is the percentual ratio between the number of samples featuring that species and the total sample number; there are accidental (1-25%), accessory (25.1-50%), constant (50.1-75%), and euconstant (>75.1%) species. The ecological significance index (W) is calculated as C×D/100; there are accidental (<0.1%), accessory (0.1-5%), and characteristic (>5.1%) species [2].

Bacteria

Bacteria are procaryotic unicellular organisms, extremely diverse in terms of biology and ecology. They are the dominant life domain on Earth, in all existing habitats, including soils.

Dan Răzvan Popoviciu
All rights reserved-© 2024 Bentham Science Publishers

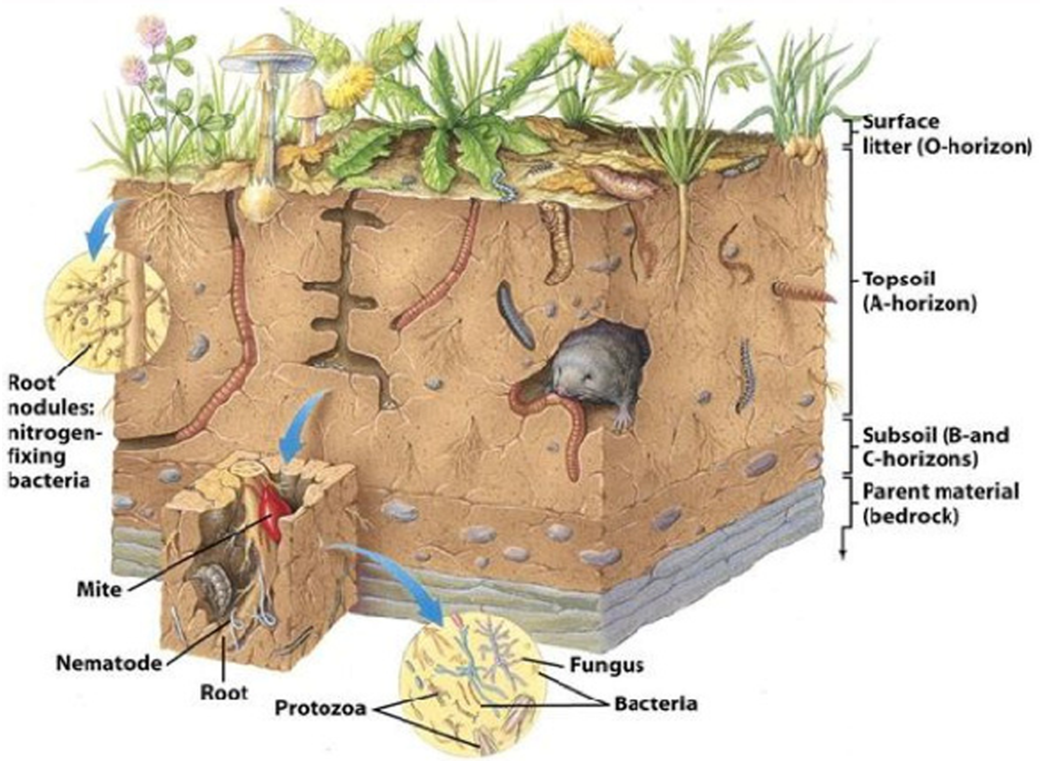

Fig. (1). Soil biodiversity [1].

Their density can be extremely variable, the limits being somewhere around 4×10^6, respectively 2×10^9 bacterial cells per gram of soil (dry mass), but can go up, under certain conditions, to about 10^{10} bacteria per gram. However, values around 10^8 cells per gram are the most common in most soil types [5, 6].

Regarding their general diversity, somewhere around 4×10^3-5×10^4 species can be found in a single gram of soil (although, of course, defining and delimiting bacterial species can be a complex topic) [5].

The density, diversity, and composition of soil microbiota depend on a wide array of factors. Among these are depth (which determines oxygen permeation), soil grain size (determines the available space, permeation of water and oxygen), mineral composition, the amount of organic matter (thus, available food), temperature, water content, and vegetation (involved in complex interactions with the local microbiota). An arid sandy soil will undoubtedly host much fewer bacteria than a muddy one. However, the differences can become significant even over small distances [5, 7].

The distribution of bacterial cells in the soil is far from uniform. The main determining factor here is the microtopography of soil grains (Fig. **3**). Pores, micro fissures, and other sheltered spaces tend to enlarge the surface available for bacterial adhesion, at the same time favoring the accumulation of organic matter.

While some bacteria are mobile, due to cilia or flagella, freely moving around in the pellicular and interstitial water, many adhere to the solid substrate, sometimes forming compact aggregates. Among adhesion mechanisms are electrostatic attraction between the components of cell walls and chemical compounds in the soil and exopolysaccharides, which cover the cell wall, either as a rigid capsule or as adhesive filaments (Fig. **3**) [8].

The ecological roles bacteria play are extremely variate.

According to their metabolism, more precisely, to the food and energy sources they employ, there are four main categories.

Photoautotrophic bacteria produce their food from atmospheric carbon dioxide, which gets fixed into organic structures by using sunlight energy. In this category, we can find cyanobacteria and a few other groups of bacteria, only present in superficial layers (where light can penetrate) of some particular soil types, especially moist ones.

Photoheterotrophs are photosynthesizing, but cannot use carbon dioxide as the sole carbon source, requiring various organic substrates. Although present in soils (*Rhodopseudomonas* sp., for instance), they are not particularly common.

Chemoautotrophs use reduced inorganic substrates to fix carbon dioxide. This category includes nitrifying and iron-oxidizing bacteria, present in many types of soil.

Chemoheterotrophs get both their necessary carbon and energy from organic substrates. Some are strictly specialized, being able to feed on just a few types of compounds, while others are rather multivalent. Within this category fits decomposing bacteria, dominant in soils, which are responsible for the very existence of soil [10].

Among ecological roles, we can mention the production of the organic components of soil, through decomposition. Also, soil microbiota mobilizes certain nutrients from their insoluble form, making them available to plants. On the contrary, other bacteria can mineralize certain chemicals, including toxins or pollutants.

CHAPTER 3

Soil Biodiversity, Macrobiota

Abstract: The most abundant multicellular organisms in the soil are fungi (although the group also contains unicellular members – yeasts). Fungi are an extremely diverse group of heterotrophic organisms. Most are saprophytic, playing key roles in decomposition and pedogenesis processes. We can add parasitic species, as well as lichens, and photoautotrophic symbiotic associations. Similar to an organization and way of life are mycetozoa and pseudofungi (oomycetes and their relatives). Plants are present in the soil only through their underground organs (roots, rhizomes, bulbs, *etc.*), but have an essential contribution to the genesis and functioning of soil, once their various underground and aboveground components decompose. Finally, animals are some of the main consumers of soil. Here we may find nematodes, annelids, insects, and other arthropods and some species of vertebrates that use soil as a temporary or permanent living environment.

Keywords: Animals, Fungi, Mycetozoa, Pseudo fungi, Plants.

INTRODUCTION

While microbial life may be dominant on Earth, in terms of numbers, other lifeforms are also key components of the biosphere.

Plants, animals, and fungi contribute with their large individual biomasses but also fill in important ecological positions: primary producers, predators, but also important decomposers.

Soils are no exception to this.

Fungi

Fungi are eukaryotic organisms, quite related phylogenetically to animals. Usually, their body is pluricellular and mycelian, formed of an extremely branched array of hyphae, which gives fungi a huge absorption surface. In some groups, parts of the hyphae come together forming pseudo-tissues called plectenchyma and even complex structures such as macroscopic fruiting bodies.

Dan Răzvan Popoviciu
All rights reserved-© 2024 Bentham Science Publishers

At the other end, some fungi (especially yeats) are single-celled and colonial, with an intermediate version of species bearing pseudo-hyphae. Very often, fungi have complex life cycles.

Up to now, at least 80,000 species and over 8,000 genera are known, of which most dwell in soils, at least partially. They form a consistent part of soil biota. Researchers estimate that fungi form 10-30% of the overall mass of rhizospheres (the soil region neighboring plant root systems).

Fungi can be either saprophytic or parasitic. They can live freely in complex symbiotic associations, such as lichens (associations with microalgae) and mycorrhizae (associations with plant roots, which will be described in another chapter) [1].

While the densest populations are found in rhizospheres, fungi are widespread in soils. Yet, they mostly inhabit the upper layers, respectively the plant litter and O horizon, due to their saprophytic regime and the need to get organic matter.

Fungi have a remarkable ecological plasticity, colonizing a wide variety of soils, from tropical rainforests to the driest deserts.

Their ecological roles are numerous. First of all, mycelial networks can perform a mechanical function, stabilizing mobile soils, which is extremely obvious in some arid regions of the world [2].

However, most of all, as decomposers, fungi are essential to the breakdown of dead organic matter and its reinsertion in trophic chains, thus, to the biogeochemical cycles of carbon and nitrogen. Fungi are able to decompose even some of the hardiest organic substances, such as lignin. They are also among the first organisms involved in breaking down plant material fallen onto the soil surface: dead leaves, fruits, *etc.*

By decomposing woody material, they create microecosystems that allow other organisms to settle in. In addition, as symbionts of plant roots, they enhance water and mineral absorption, and plant productivity, but also resistance to disease and adverse pedological conditions. Last but not least, parasitic fungi are also important for trophic chains at the soil level [2].

Fungal taxonomy is extremely complicated (Fig. **1**), but, traditionally, this phylum is divided into three main groups: Zygomycota, Ascomycota, and Basidiomycota, to which we may add the Deuteromycota, a mysterious and probably polyphyletic grouping of all fungi that seemingly lack any kind of sexual reproduction.

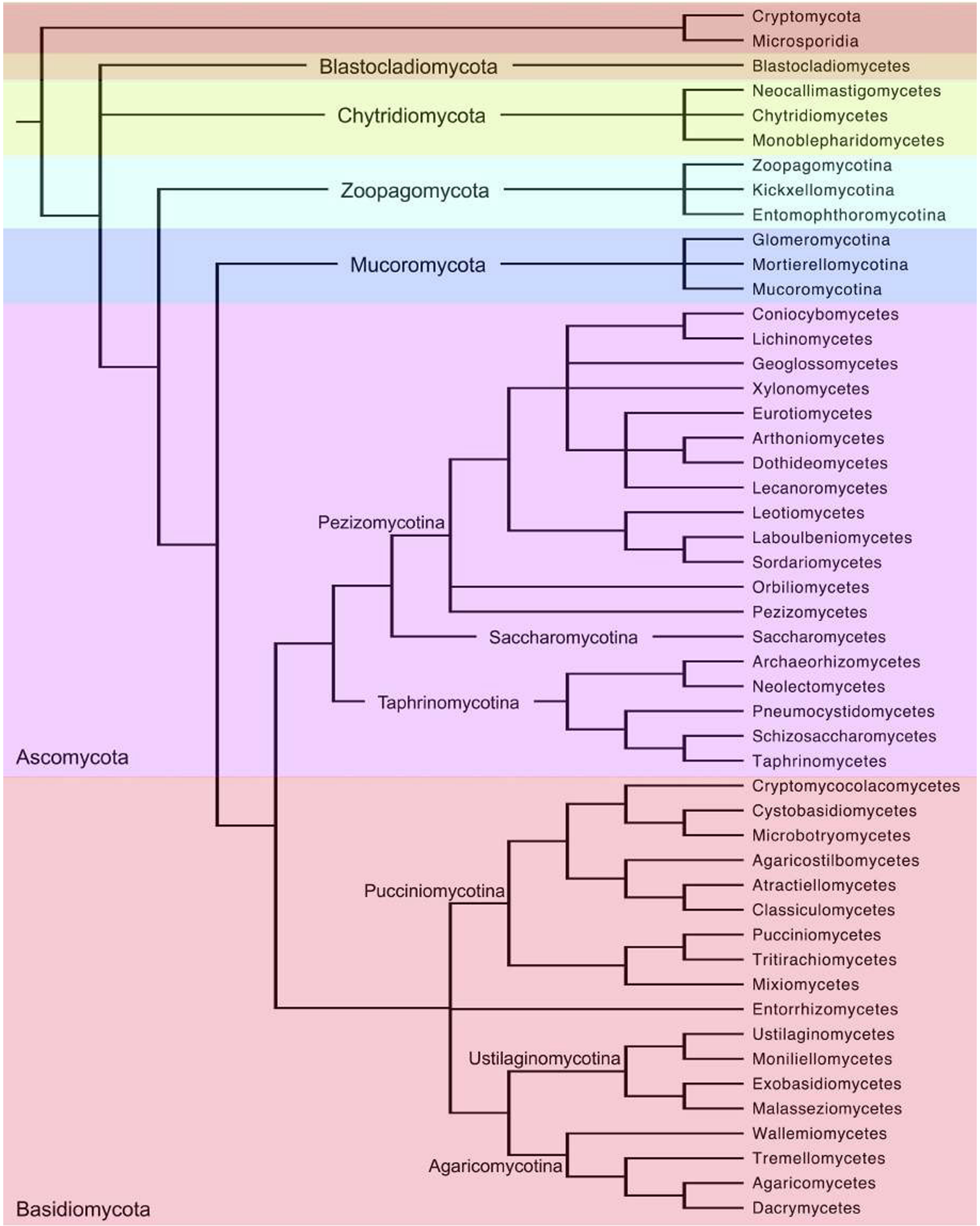

Fig. (1). The phylogenetic tree of fungi [3].

CHAPTER 4

Cycles of Matter in Soil, Carbon Cycle

Abstract: The entire organic chemistry is based on carbon, an essential element in all substances that form living matter. The carbon cycle in soil comprises a wide variety of processes, involving diverse groups of micro- and macroorganisms. Photoautotrophy and chemoautotrophy are weakly represented, although they are not a negligible source of organic matter. The dominant process, however, is decomposition. Sugars, lipids, proteins, and other categories of compounds are being constantly degraded, through the enzymatic activity of various heterotrophic microorganisms, forming humus (a relatively stable organic complex) and, then, simpler and simpler products. In weakly oxygenated soils, specific phenomena such as methanogenesis and its reverse, methanotrophy, occur.

Keywords: Chemosynthesis, Carbon, Decomposition, Humus, Methanogenesis, Methanotrophy, Photosynthesis.

INTRODUCTION

As shown above, soil is a complex and open system, in which matter undergoes continuous transformations and which has a constant exchange of chemicals, organisms, and energy with other environments. And yet, like any other ecological system on Earth, it maintains its characteristics and equilibrium in the long term.

All these are due to the continuous recycling of the various biogenic chemical elements. Living beings are a key component of these cycles, through processes such as photo- and chemosynthesis, trophic relationships (prey-predator), and decomposition.

Organic matter is an essential component of soil and carbon is the essential component of organic matter. It includes hydrocarbons and derivatives, lipids, sugars (mono-, oligo-, polysaccharides), alcohols, ketones, acids, amino acids, peptides (mono-, oligo-, polypeptides), proteins, nucleotides, and nucleic acids.

Basically, soil contains organic matter under active decomposition, stabilized organic matter (meaning humus, with a low rate of breakdown processes) – each of these two fractions composing between 33 and 50% of the total mass, as well

Dan Răzvan Popoviciu
All rights reserved-© 2024 Bentham Science Publishers

as fresh organic residues beginning their decomposition cycle (up to 10%) and, of course, the biomass of indigenous micro- and macroorganisms (below 5%) [1].

Besides organic matter, carbon is an important component of the atmosphere (as carbon dioxide, with a concentration of 0.04%) and also of hydrocarbon deposits in the deep lithosphere. Between these forms of carbon, organic and inorganic, there is a continuous biogeochemical circuit that involves among others the biosphere (including humankind), of which soil biota is a consistent part (Figs. **1** and **2**).

The carbon cycle includes a series of biological processes, including some that occur at the soil level: autotrophy (photosynthesis and chemosynthesis), decomposition, trophic relationships, and respiration. In the following subchapters, we will analyze some of them.

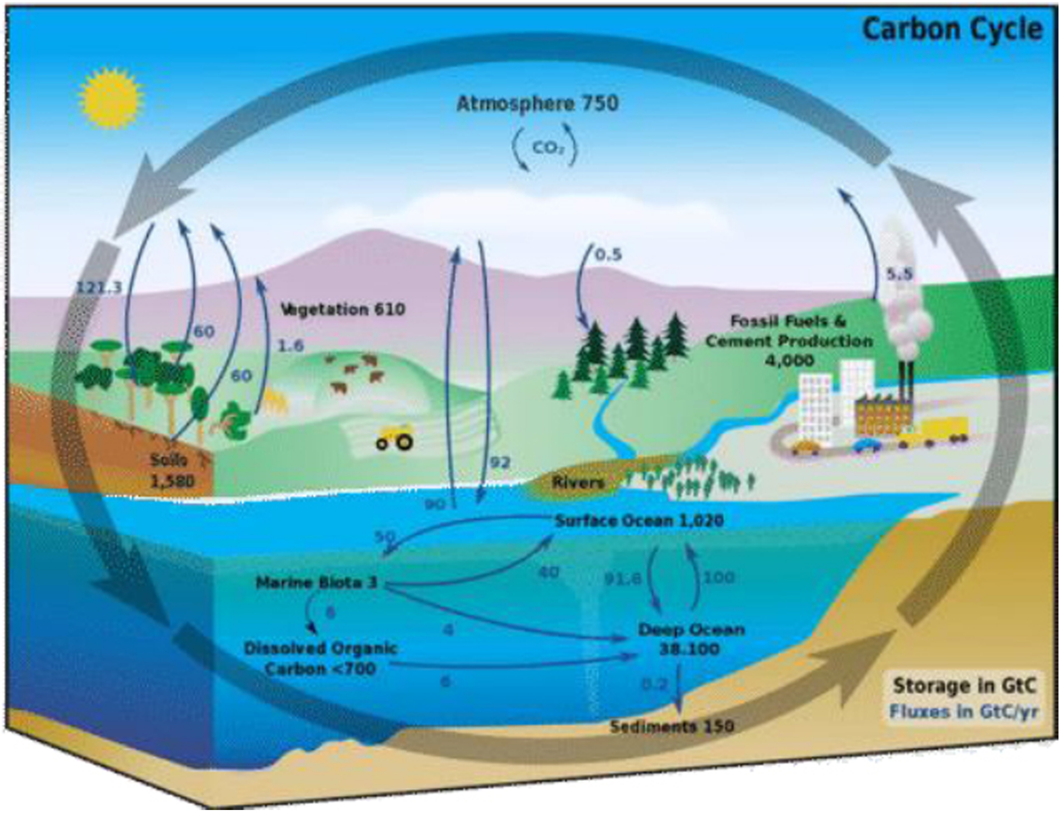

Fig. (1). The global carbon cycle [2].

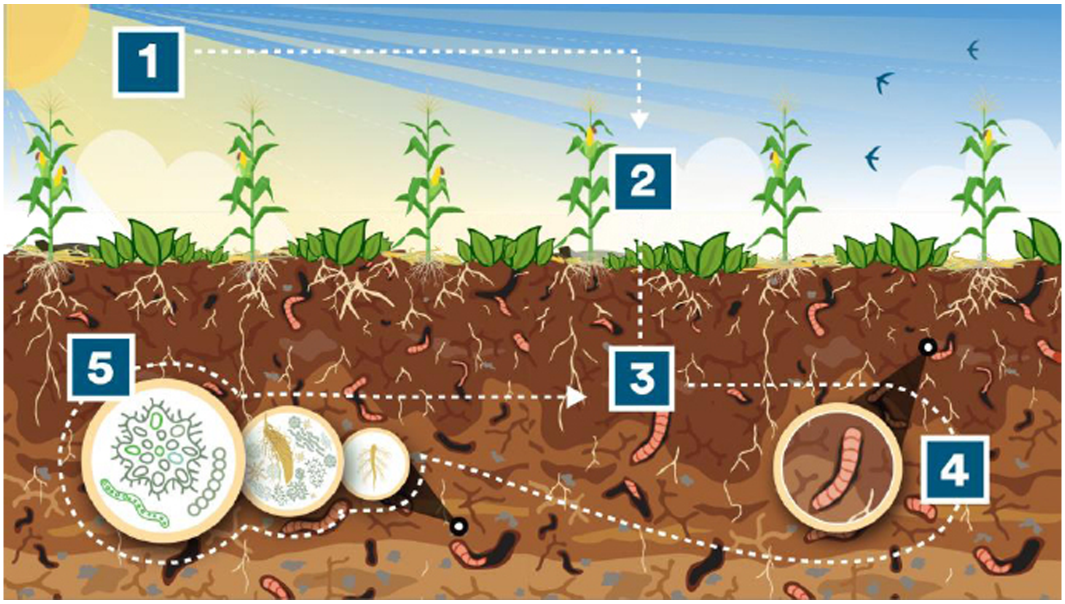

Fig. (2). Soil carbon cycle: 1. atmospheric CO_2, 2. photosynthesis, 3. root exudate secretion, 4. descomposition and aggregation of organic matter by macroorganisms (nematodes, andelids), 5. microbial decomposition of organic matter [3].

Photosynthesis

Photosynthesis is the autotrophic feeding process, through synthesizing organic compounds from CO_2, by using sunlight energy, which in turn is aquired through specific assimilatory pigments (chlorophylls, bacteriochlorophylls, carotenoids, *etc.*)

It can be oxygenic (the most common form, found in cyanobacteria, algae, and plants, where water is the hydrogen donor; Fig. (**3**) or anoxygenic (in some groups of bacteria, having H_2S or other compounds as hydrogen donors).

Responsible for producing organic matter through this process, in soils, are bacteria (especially cyanobacteria), microalgae, and lichens, as shown in chapters 2-3. In some arid areas, these are the main sources of soil organic matter [6].

However, usually, just a small fraction of this process occurs in the upper layers of soil. In most terrestrial environments, plants are the main primary producers and the compounds they synthesize reach soil only by means of their root secretions or decomposition of dead organs.

CHAPTER 5

Cycles of Matter in Soil, Nitrogen Cycle

Abstract: Nitrogen is another bioelement of crucial importance, being a part of amino acids, proteins, nucleic acids, and many other organic compounds. It is also an object to a complex natural cycle occurring, among others, at the soil level. Ammonification is one of the main components of this cycle, consisting of the decomposition of nitrogen-containing organic compounds and releasing ammonium ions, essential nutrients for plants and microorganisms. Another nitrogen input source in soils is the fixation of atmospheric dinitrogen by some bacteria, free-living or in symbiosis with certain plant species. Nitrification converts ammonium into nitrate, another valuable nutrient, soluble and easily disseminated in soil solution and hydrosphere. Microbial denitrification closes the cycle by transforming nitrate into nitrogen oxides and, then, dinitrogen that returns to the atmosphere.

Keywords: Ammonification, Denitrification, Fixation, Nitrification, Nitrogen.

INTRODUCTION

Nitrogen is one of the most important biogenic elements. It is part of some common organic and inorganic substances. First of all, as molecular nitrogen or dinitrogen (N_2), it forms 78% of the Earth's atmospheric mass. Nitrogen oxides (NO, NO_2, N_2O) are other components of our atmosphere, albeit minor ones, due to their instability.

In water and soils, various nitrogen salts are found, such as those featuring the nitrate (NO_3^-), nitrite (NO_2^-) and ammonium (NH_4^+) ions. Organic nitrogen compounds are much more variate, including amines, amides aromatic nitrogen compounds, enamines, nitramines, nitriles, imines, nitrosamines, organic nitrates, some vitamins and alkaloids, but most importantly, amino acids, peptides, proteins, nucleobases, nucleotides and their polymers, nucleic acids [2].

All these compounds undergo continuous syntheses and degradations, thus ensuring both the necessary nutrients to all lifeforms on Earth and maintaining the normal composition of the atmosphere. This is the biogeochemical cycle of nitrogen, whose four stages occur in diverse environments, including soil (Fig. (**1**).

Dan Răzvan Popoviciu
All rights reserved-© 2024 Bentham Science Publishers

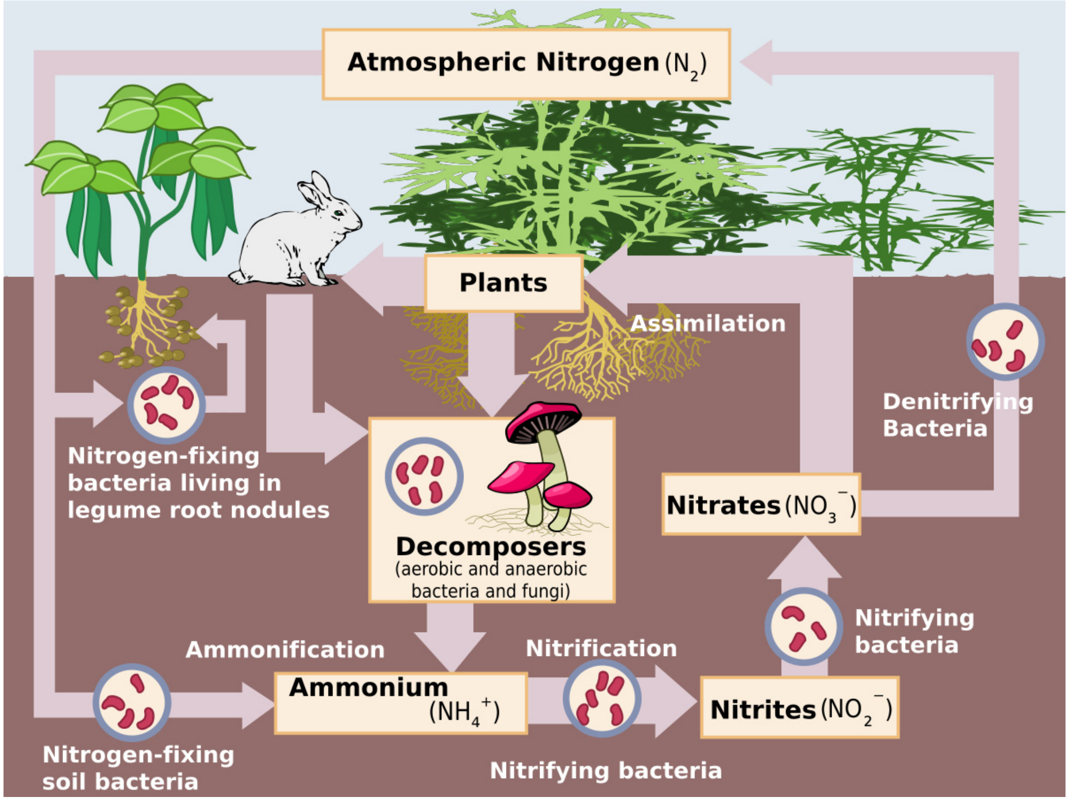

Fig. (1). Nitrogen cycle in soil [1].

Ammonification

Ammonification or nitrogen mineralization is a key process, leading to the release of nitrogen from various organic compounds and its conversion into ammonium ion (NH_4^+) salts; these salts are water-soluble and easily accessible to primary producers (especially to plants).

It is actually a form of decomposition of these substances (mostly byproducts of protein and nucleic acids breakdown). It is mostly due to bacteria. Among the main ammonifiers, we may find Gram-positive species (genera *Bacillus* and *Clostridium* and, most of all, actinomycetes), or Gram-negative ones (genera *Pseudomonas*, *Serratia*, *Vibrio, etc.*) [3].

There are also some fungi involved in this process, such as species of *Alternaria*, *Aspergillus* or *Mucor*. All these organisms can degrade proteins and their subdivisions, by secreting proteases (proteolytic enzymes, see previous chapter). Furthermore, the production of ribonucleases and deoxyribonucleases, allows the breaking down of nucleic acids.

However, these are not the only sources of organic nitrogen. Urea (a byproduct of decomposition, but also a commonly used fertilizer) is degraded by ureases, produced by certain species of *Bacillus*, *Micrococcus*, *Proteus,* or *Sarcina*. Amines are the target of aminooxidases produced by species of *Mycobacterium*, *Protoaminobacter,* and *Pseudomonas*. Amides are hydrolysed by amidases and, among the organisms responsible for this, we can mention the green alga *Chlorella* sp [4].

Populations of ammonifying microorganisms in the soil (mainly bacteria) commonly reach densities of $1\text{-}5\times10^6$ culturable organisms per gram of dry soil (real densities being, probably, much higher) [5]. The total amount of mineralized nitrogen is usually a few milligrams per kilogram of soil per day (between 0.3-9 mg/kg/day, for instance, in a study conducted on different types of soils in tropical and temperate regions of China) [6].

Among the factors that may determine the density and composition of ammonifying microbiota, as well as its efficiency, we should mention agricultural practices. Fertilization with urea, for instance, tends to enhance ammonification, while mineral amendments (calcium chloride, potassium sulfate) may have mixed effects. Likewise, mixed effects can be due to pesticides: some enhance the responsible microbiota (just up to a specific dose), while others inhibit it. Ecological crops seem to yield higher ammonification rates than conventional ones [7 - 9].

Nitrogen Fixation

One of the most interesting and important processes in the living world is the biological fixation of nitrogen (diazotrophs). Dinitrogen (N_2), a molecule rather chemically inert, makes up around 78% of our planet's atmosphere. However, in this state, it is not truly bioavailable. Its conversion to more accessible compounds is done electrically (by lightning) or by using nitrogenases, enzymes specific only to some groups of bacteria.

These complex enzymes, containing iron and, often, molybdenum or vanadium ions, can catalyze the reduction of nitrogen to ammonium, which, in turn, will be used in organic syntheses. Molecular oxygen, above a certain concentration, inhibits the enzymes so the microorganisms involved need to find various protection mechanisms: thick cell walls, abundant mucus, enzymes that immobilize oxygen, or symbioses with other lifeforms.

Diazotrophy is not really a common feature, but not even a very rare one. It is found in diverse groups of bacteria, some are aerobic, others are microaerophilic

CHAPTER 6

Cycles of Matter in Soil: Phosphorus, Sulfur, Metals

Abstract: Phosphorus and sulfur, together with alkaline, alkaline earth and transitional metals are important nutrients and constituents of living matter. The sulfur cycle involves an atmospheric phase, but its main stages are due to terrestrial biota, through processes like sulfate reduction, sulfide oxidation, anoxygenic photosynthesis, *etc.* The cycles of phosphorus and metals lack significant atmospheric stages. The main biogeochemical processes involving soil microorganisms are those of solubilization and precipitation, that determine their general bioavailability.

Keywords: Potassium, Phosphorus, Calcium, Sulfur, Sodium, Transitional metals.

INTRODUCTION

While carbon and nitrogen (together with oxygen and hydrogen, of course) are the main bioelements, found in all organic compounds, they are not alone.

The “recipe” of life also includes other key ingredients like phosphorus or sulfur, but also oligo- and microelements, including a wide variety of metals: sodium, potassium, calcium, iron, manganese, copper, *etc.*

All these bioelements are subjected to continuous recycling in soil. Furthermore, oxidoreductive processes involving some of them (like transitional metals) provide a source of energy for various microorganisms.

Phosphorus Cycle

Phosphorus is one of the key ingredients of living matter. Phospholipids that make up cell membranes, adenosine triphosphate/diphosphate that is used by all organisms to store their energy, as well as DNA, and RNA, essential to storing and transmitting genetic information, are just a few examples.

Dan Răzvan Popoviciu
All rights reserved-© 2024 Bentham Science Publishers

Besides these, phosphorus is a quite common constituent of minerals in the Earth's crust, especially apatites ($Ca_5(PO_4)_3X$; hydroxy-/chloro-/fluoroapatites), strengite, and variscite. A certain amount of such minerals is also found in soils.

Yet, the most common form of inorganic phosphorus compound in soil is that of orthophosphates (PO_4^{3-}). Part of these salts is found adsorbed on clay particles and iron, calcium, and aluminium ions. They can be slowly released into the soil solution, thus becoming bioavailable to plants and microorganisms. Finally, there are some soluble phosphates in the soil solution (albeit not in high concentrations), which are easily bioavailable [1 - 3].

It is easy to notice that this cycle lacks an atmospheric component. Actually, there is a gaseous compound, phosphine (PH_3), produced by some microorganisms, as well as industry, but in very low amounts.

The main phosphorus source in the soil is the decomposition of dead organic matter (see previous chapters), a process due to a wide array of bacteria, fungi, *etc.* Also, in agroecosystems, some important sources are chemical or biological (especially poultry manure) fertilizers.

Besides decomposition, microorganisms are involved in other two important phases: phosphorus precipitation in insoluble forms, and its mobilization (solubilization; Fig. **1**) [1 - 6].

Phosphorus Solubilization

Insoluble forms of phosphorus are hardly available to living organisms. This can be remediated by secreting organic acids, phosphatases, or hormones, that can mobilize phosphorus (as phosphate ions) in chemical forms that are more soluble and easier to transport by soil solution.

Part of this process is due to plants, through their own radicular secretions. Another part involves microorganisms, especially **phosphate-solubilizing bacteria** (PSB). Finally, a substantial part is due to the interspecific collaboration between plant root systems and microbial associations within the immediately neighbouring soil region, an environment called the rhizosphere (see the next chapter). Plant secretions favor solubilizing microbiota, which, in turn, mobilizes phosphates in soil.

The process is of extreme importance to plant growth (thus, also to agricultural productivity), since phosphorus is an essential nutrient, absorbed in large amounts and with a tendency to be depleted fast around roots, at least in its easily accessible forms [2, 5, 6].

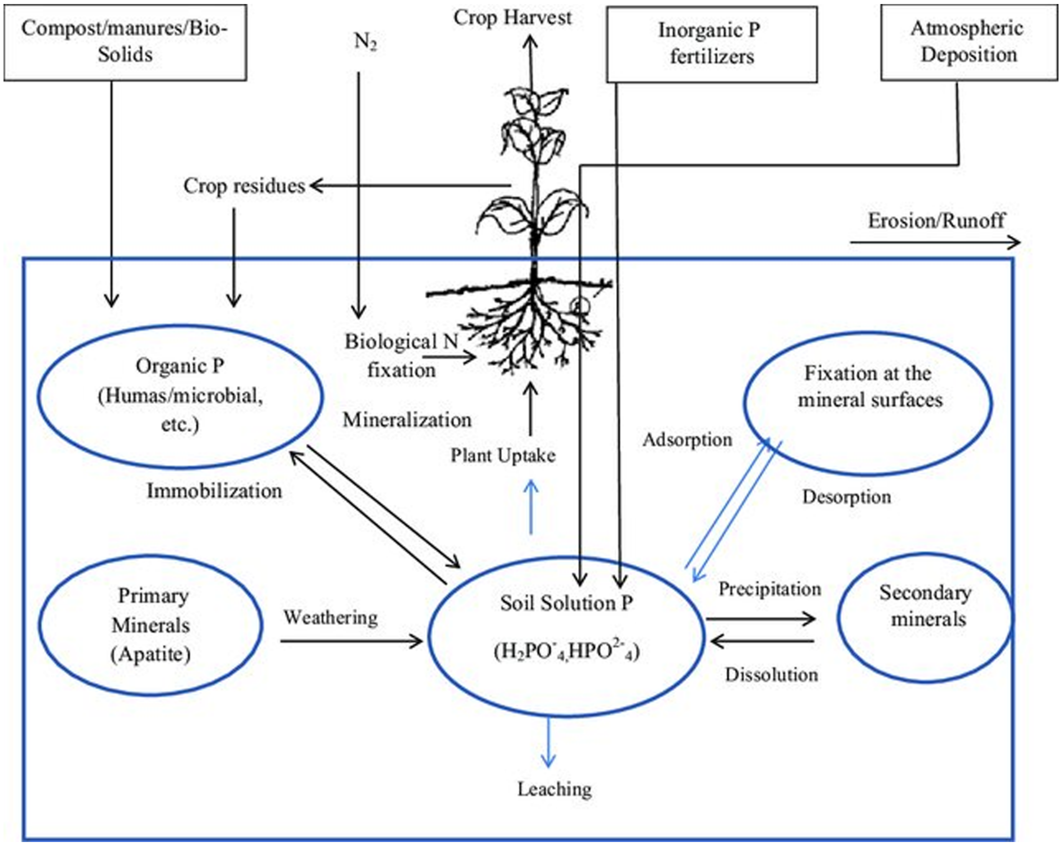

Fig. (1). Phosphorus cycle in soil [7].

Among the bacteria involved are members of the genera *Azotobacter*, *Bacillus*, *Beijerinckia*, *Burkholderia*, *Enterobacter*, *Erwinia*, *Flavobacterium*, *Microbacterium*, *Pseudomonas*, *Rhizobium* and its relatives or *Serratia*. Among fungi, we can mention *Aspergillus* sp. and *Penicillium* sp. Their main way of action is by secreting acids (rich in carboxyl and hydroxyl groups), that chelate metals associated with phosphate, thus releasing the latter into the soil solution. Other mechanisms involve direct oxidations, acidification of soil solution, the use of enzymes to release phosphate from organic structures, *etc.* (Fig. **2**).

As mentioned above, the process is extremely important and knowledge of these microorganisms is of great value for agriculture: inoculation with PSB may significantly enhance crop output in soils with low phosphorus levels (for instance, in calcareous soils, where it tends to precipitate easily). Thus, those microorganisms can be used as biofertilizers [6, 9].

CHAPTER 7

Ecological Relationships Between Soil Organisms, Symbioses, Applications of Soil Ecology

Abstract: Between soil organisms, various interspecific relationships are formed, some of which are positive, and others are negative for at least one of the parts involved. A mutually positive relationship is symbiosis. Endo- and ectosymbioses between nitrogen-fixing bacteria and plant roots, actinorrhizae, and, most of all, mycorrhizae play extremely important roles in plant productivity and maintaining soil quality. Relationships between plants and various groups of microorganisms at the rhizosphere level also ensure a matter and energy flow from one plant to another, leading to a true „mycorrhizal Internet". Knowledge and control over these complex relationships also have practical applications, in producing biofertilizers, biopesticides, and in bioremediation, *etc.*

Keywords: Interspecific relationships, Mycorrhizae, Rhizosphere, Symbiosis.

INTRODUCTION

Just like in any other environment, organisms that inhabit soil do not live isolated. They depend on each other, through a wide array of interspecific interactions.

Some of these relationships are negative for at least one of the partners. The most obvious that come to our minds are predation or parasitism.

Yet, many other such interactions are positive, or even essential to both sides involved and, first of all is symbiosis.

Types of Interspecific Ecological Relationships

The various organisms that inhabit any particular environment, including soil, can establish a wide variety of relationships.

Among the **positive**, or **associative** ones (beneficial for both parties involved) we can mention metabiosis, symbiosis, and commensalism.

Dan Răzvan Popoviciu
All rights reserved-© 2024 Bentham Science Publishers

Metabiosis is an indirect positive relationship: an organism alters the surrounding environment, through its metabolism, thus creating favorable conditions for another one (Fig. **1**). For instance, plants bring organic matter into the soil, thus contributing to pedogenesis and feeding a wide array of microorganisms. Earthworms aerate soils, favoring aerobic microbiota there. Some bacteria and plants help clean up pollutants from the soil, making it accessible again to the more sensitive species.

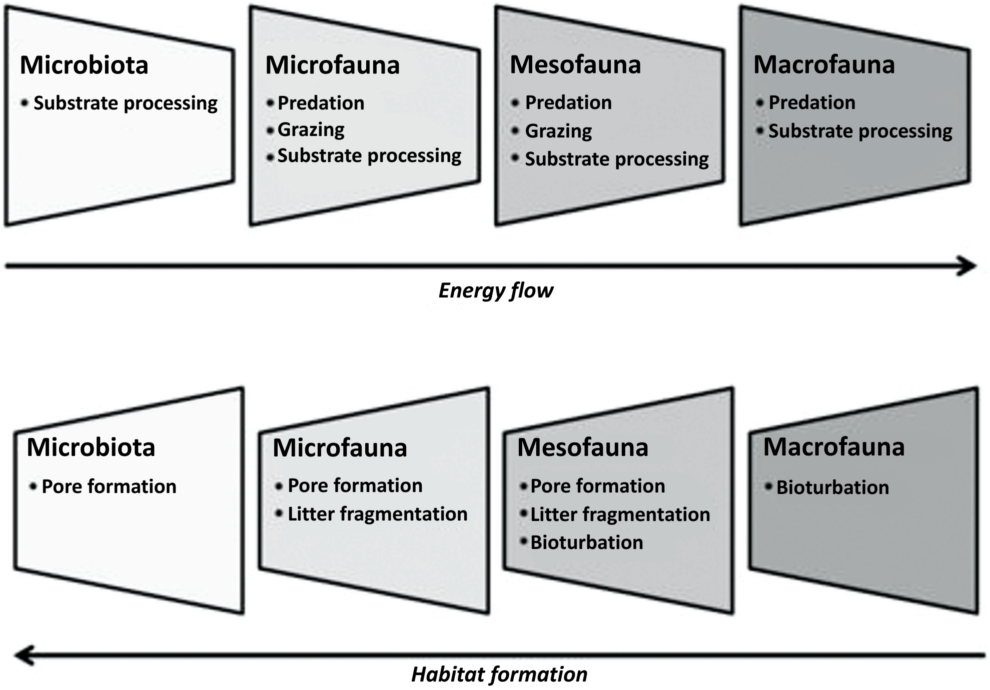

Fig. (1). Participation of soil biota in habitat alteration and energy flows [4].

In a wider sense, **symbiosis (mutualism)** is a relationship strictly necessary for at least one of the parts to thrive. In a stricter sense, we are talking about a relationship that is both compulsory and beneficial to both sides involved. Lichens, legume nodules (hosting nitrogen-fixing bacteria), actinorrhizae, and mycorrhizae are good examples of fruitful symbioses developed over millions of years of evolution (see subchapter 7.2).

Commensalism briefly means “to eat at someone else’s table”; a coexistence profitable for one of the partners and indifferent to the other. For example, dead plant organs and root exudates provide food for the heterotrophic microbiota.

Among the **negative** relationships, we can mention amensalism, antibiosis, and predatorism.

Amensalism is neutral to one of the partners but harmful to the other. Many species can alter their environment (without any notable benefit for themselves), inhibiting the growth of other organisms. Acidification of soil solution by some acidophilic bacteria (*Thiobacillus* sp.) reduces the microbial populations that are less tolerant to low pH values [1 - 3].

Antibiosis is an active form of amensalism. An organism intentionally secretes toxins or inhibitors in order to wipe out any competition. The phenomenon is widespread among bacteria, fungi (*Penicillium* sp. being the best example) and even plants.

Competition occurs when more organisms compete for the same resources – especially trophic resources – and is stronger when the the amount of those resources is limited. For instance, a nitrogen deficit will cause a ruthless race between plants and microorganisms for that limited amount.

Finally, **predatorism** is mainly specific to protozoa and animals. An organism eats another and the same phenomenon occurs at successive, overlaying levels, leading to the formation of trophic chains (Fig. **2**). Such chains usually include primary producers, consumers of various levels, and decomposers.

A specific form of predatorism is **parasitism**, meaning that an organism can only thrive on behalf of another (its host) [1 - 3].

Symbioses

Nitrogen-fixing nodules

One of the main examples of symbiotic relationships present at the soil level is between legumes and nitrogen-fixing bacteria generally known as "**rhizobia**".

The plants involved are all part of the family Fabaceae (and the vast majority of the species in this family are involved). Rhizobia, on the other hand, is actually a very diverse group of bacterial taxa. Most are α-proteobacteria, belonging to several closely related genera, such as *Bradyrhizobium*, *Mesorhizobium*, *Rhizobium*, *Agrobacterium*, and *Sinorhizobium*. In some tropical legumes, such as those in the genus *Mimosa*, some of the endosymbionts may belong to β-proteobacteria: *Burkholderia*, *Cupriavidus*, and *Paraburkholderia*.

SUBJECT INDEX

Dan Răzvan Popoviciu
All rights reserved-© 2024 Bentham Science Publishers